AD-A104 243 GENERAL ELECTRIC CO BINGHAMTON N Y AIRCRAFT EQUIPMENT DIV F/G 17/2
ELECTRONIC MASTER MONITOR AND ADVISORY DISPLAY SYSTEM, DATA TRA--ETC(U)
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UNCLASSIFIED ACS12-177 USAAVRADCOM-TR-79-0270-1 NL

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Technical Report 79-0270-1

ELECTRONIC MASTER MONITOR AND ADVISORY DISPLAY SYSTEM, DATA TRANSMISSION STUDY.

GENERAL ELECTRIC COMPANY
AIRCRAFT EQUIPMENT DIVISION
BINGHAMTON, NY 13902

AUG [redacted]80

FIRST INTERIM REPORT. [redacted] JUN 79 – AUG 80.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AVRADCOM-TR-79-0270-1	2. GOVT ACCESSION NO. AD-A104 243	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Electronic Master Monitor And Advisory Display System, Data Transmission Study		5. TYPE OF REPORT & PERIOD COVERED R&D June 79 - Aug 80
		6. PERFORMING ORG. REPORT NUMBER ACS12-177
7. AUTHOR(s)		8. CONTRACT OR GRANT NUMBER(s) DAAK-80-79-C-0270
9. PERFORMING ORGANIZATION NAME AND ADDRESS General Electric Co. Aircraft Equipment Division Binghamton, NY 13902		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L2-662202-AH85-03-12-31
11. CONTROLLING OFFICE NAME AND ADDRESS Avionics R&D Activity Communications, Sensors, Instrumentation Division		12. REPORT DATE Aug 1980
		13. NUMBER OF PAGES 55
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCL
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

MONITOR,	AIRCRAFT
DISPLAYS,	SUBSYSTEMS
DATA BUS	FIBER OPTICS
ADVISORY DISPLAYS	MULTIPLEX

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The development of non-mission-related status information is one area of rotary wing instrumentation which has not kept pace with the state-of-art. This includes raw data, discrete and summary status information related to the engine, transmission, rotor, fuel, hydraulic and electrical subsystems. The objective of this report is to define an efficient and cost effective data transmission method for an Electronic Master Monitor and Advisory Display System (EMMADS). Several current standard and non-standard data bus

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specifications which are applicable to the EMMADS system are introduced. Their tradeoff in terms of hardware, software and system considerations are compared.

It should be noted that a typical standard bus specs addresses only the protocol and message formats, not the mechanization of the control algorithm. Hence there is a considerable variation in implementation and cost even for the same bus standard. The materials represent a snapshot of the current state-of-the-art technology. The use of optical fiber instead of conventional electrical cable (such as coaxial) as the transmission medium is also investigated based on the current technical reports. The problems of electromagnetic interference (EMI), and rejection techniques are mentioned. Conclusions and recommendations of this task are presented

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Section 1
INTRODUCTION

The principle objective of this study is to define an efficient and cost effective data transmission method for an Electronic Master Monitor and Advisory Display system (EMMADS). By contractual requirement the EMMADS demonstration hardware will use a dual redundant MIL-STD-1553B General Purpose Multiplex System (GPMS) as the basic transmission interface between the EMMADS and the other helicopter subsystems. There are many data transmission methods which are suitable for the EMMADS type system, so to make an intelligent decision concerning data transmission problem, it is essential to address the following two questions:

1. Can EMMADS data transmission be handled comfortably by the 1553B data bus?

2. Is the 1553B bus the best choice among all the alternatives?

To answer the first question, the EMMADS data bus requirement must be defined. This has been done in the Task I (Signal Analysis) of the EMMADS contract which identifies basic subsystem functional and information requirements for cargo (CH-47C), utility (UH-60A), scout (OH-58C) and attack (YAH-64) helicopters. A brief summary of that task and its results is presented in Section 2.

Several current standard and non-standard data bus specifications which are applicable to the EMMADS system are introduced in Section 3. Their tradeoff in terms of hardware, software and system considerations are compared in Section 4. It should be noted that a typical standard bus specs addresses only the protocol and message formats, not the mechanization of the control algorithm.

Hence there is a considerable variation in implementation and cost even for the same bus standard. Therefore the materials in Section 4 represents only a snapshot of the current state-of-art technology.

In addition to the two questions above, the use of optical fiber instead of conventional electrical cable (such as coaxial) as the transmission medium is also investigated based on the current technical reports. The various aspects of fiber optics technology and the evaluation of its usage as the EMMADS data communication link are included in Section 5.

The problems of Electromagnetic interference (EMI), and rejection techniques are briefly mentioned in Section 6. The conclusions and recommendations of this task are presented in Section 7.

Section 2
EMMADS DATA BUS TRANSMISSION REQUIREMENT

2.1 DATA TYPE AND SOURCE

Extensive work has been done for Task I (Signal Analysis) to identify what data is needed, where it comes from and when it is to be used by the EMMADS System. In terms of data collection to be discussed later, parameters such as temperature, pressure, speed, quantity, electrical power and metallic chip detection are categorized and tabulated under the system area where the information is gathered.

There are seven system areas common to all four types of helicopter (UH-60A, CH-47C, OH-58C and YAH-64). Sensors related to each of these subsystems are the data sources which provide the necessary raw data to the EMMADS processor. The seven systems are: (1) engine, (2) fuel, (3) power train, (4) hydraulic, (5) electrical, (6) miscellaneous and (7) APU subsystem. Figure 1 shows, as an example, these basic systems in relation to their positions on the CH-47C helicopter. The first five system areas are easy to identify because they are directly related to the flight capability of the aircraft. The last two vary depending on aircraft's type and size. Another example is the YAH-64 as depicted in Figure 2.

2.2 EMMADS DATA REQUIREMENT

The results of Task I (Signal Analysis) indicate that there are 70-120 parameters on a large helicopter and about 40 parameters on a small helicopter which would be monitored by the EMMADS. As more equipment is added the monitored items will increase. Using the YAH-64 as an example of data collected on a helicopter, 108 parameters would be monitored and transmitted to the EMMADS processor. In Table 1, these paramters are listed under the

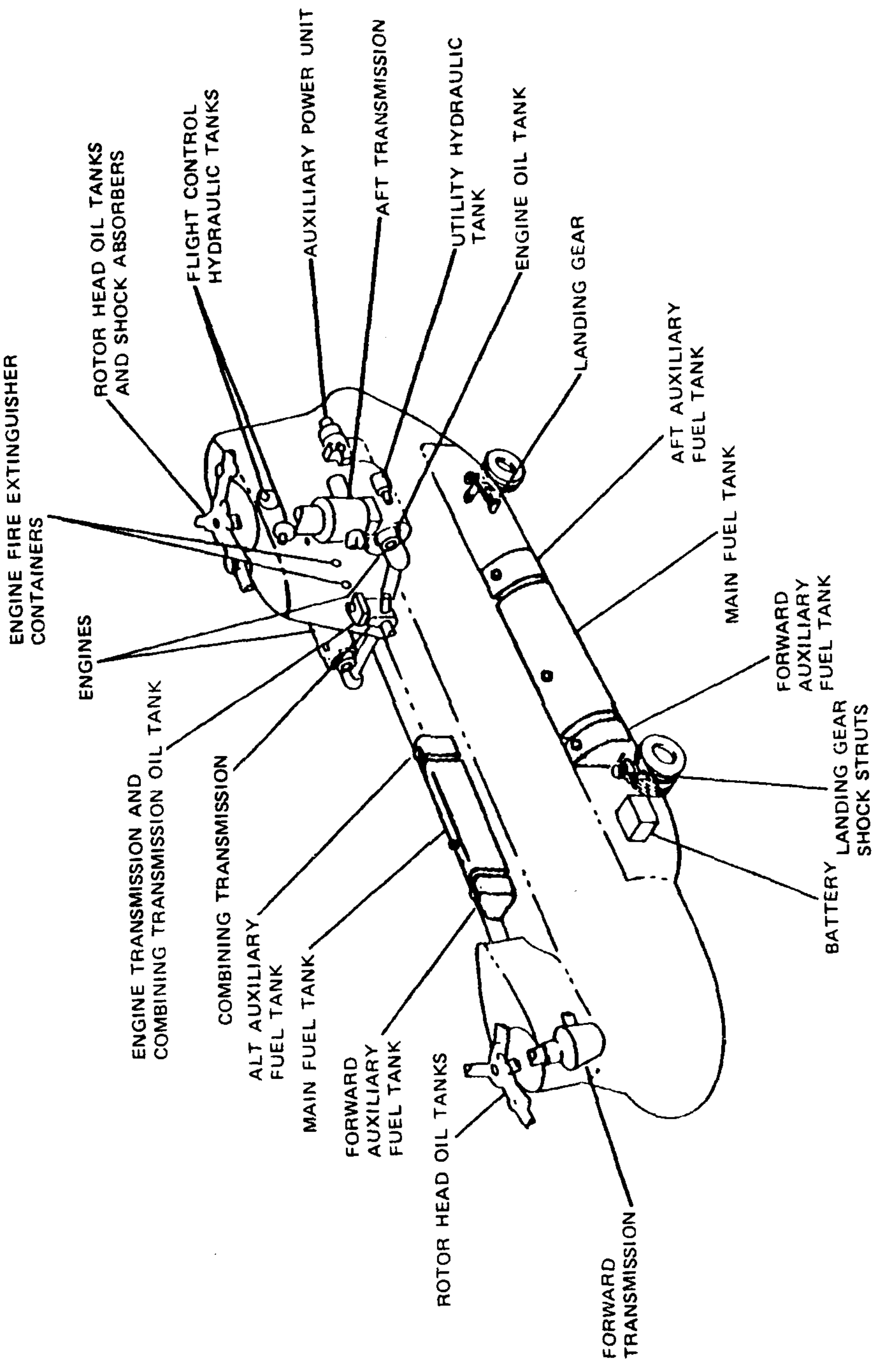

Figure 1. CH-47C Helicopter

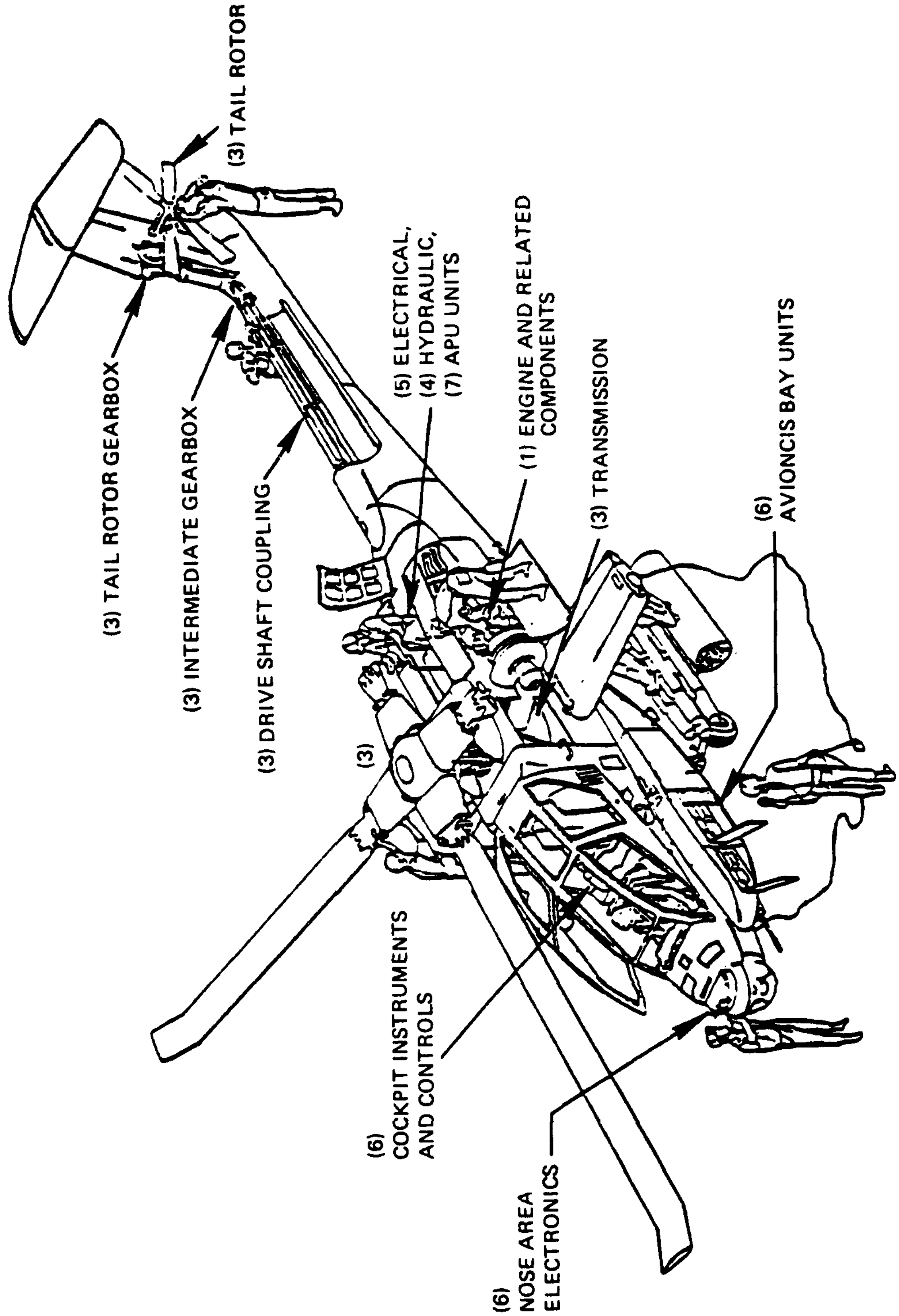

Figure 2. YAH-64 Helicopter

system area in which they originate along with the signal type (analog or discrete), data length (word or bit), and location/ remark. In order to derive a quantitative requirement for the EMMADS Data Bus Transmission, Table 1 will be referenced as the hypothetical EMMADS Data Requirement.

A check of Table 1 shows the data requirement to be as follows: (1 word is defined to be 16 bits)

1. Engine
   Analog - 12 words
   Discrete - 16 bits (to be packed as one word)

2. Fuel
   Analog - 2 words
   Discrete - 10 bits (one word, 6 spare bits)

3. Power train
   Analog - 1 word
   Discrete - 19 bits (two words, 13 spare bits)

4. Hydraulic
   Analog - 3 words
   Discrete - 6 bits (one word, 10 spare bits)

5. Electrical
   Analog - 4 words
   Discrete - 11 bits (one word, 5 spare bits)

6. Miscellaneous
   Discrete only - 20 bits (two words, 12 spare bits)

7. APU
   Analog - 1 word
   Discrete - 3 bits (one word, 13 spare bits)

TABLE 1
EMMADS DATA REQUIREMENT (BASED ON YAH-64)

SYSTEM PARAMETERS	SIGNAL	DATA LENGTH	LOCATION/REMARK
ENGINE:			LOCATION: TWO ENGINES & ENGINE CONTROL UNITS
POWER TURBINE SPEED	ANALOG	2 WORDS	
GAS TURBINE SPEED	ANALOG	2 WORDS	
POWER TURBINE INLET GAS TEMP	ANALOG	2 WORDS	
TORQUE	ANALOG	2 WORDS	NOTES:
OIL TEMPERATURE	ANALOG	2 WORDS	*WILL NOT BE INCLUDED IN EMMADS.
OIL PRESSURE	ANALOG	2 WORDS	
OIL PRESSURE LOW	DISCRETE	2 BITS	
OIL FILTER BYPASS	DISCRETE	2 BITS	**THESE ARE ADVISORY LIGHTS CURRENTLY ON CONTROL PANEL AND MAY NOT GO ON EMMADS.
CHIP IN SCAVENGE OIL	DISCRETE	2 BITS	
OIL TEMP HIGH	DISCRETE	2 BITS	
ENGINE FAIL	DISCRETE	2 BITS	
ENGINE FIRE*	DISCRETE	2 BITS	
ENGINE ICE	DISCRETE	1 BIT	
ANTI-ICE HOT ENGINE INLET	DISCRETE	1 BIT	
ANTI-ICE BLEED VALVE POSITION**	DISCRETE	2 BITS	
FUEL:			REMARKS: MULTIPLE TANKS
FUEL QUANTITY (FWD & AFT)	ANALOG	2 WORDS	
EXTERNAL FUEL TANKS*			NOTES:
- EMPTY	DISCRETE	2 BITS	*PRESENCE OF EXTERNAL TANK IS NOT CURRENTLY INDICATED. THIS REPRESENTS THE BEST ESTIMATE OF ADDITIONAL DATA REQUIREMENT IF THESE TANKS ARE INCLUDED.
- PRESSURE	DISCRETE	2 BITS	
FUEL FILTER BYPASS	DISCRETE	2 BITS	
FUEL LOW (FWD & AFT)	DISCRETE	2 BITS	
BOOST PUMP ON	DISCRETE	1 BIT	
REFUEL VALUE OPEN	DISCRETE	1 BIT	

TABLE 1 (CONT)
EMMADS DATA REQUIREMENT (BASED ON YAH-64)

SYSTEM PARAMETERS	SIGNAL	DATA LENGTH	LOCATION/REMARK
POWERTRAIN:			
			LOCATION:
ROTOR SPEED	ANALOG	1 WORD	ROTOR GEAR BOX
ROTOR RPM HI	DISCRETE	1 BIT	MAIN TRANSMISSION
ROTOR RPM LOW	DISCRETE	1 BIT	NOSE GEAR BOX
ROTOR BRAKE	DISCRETE	1 BIT	
INTERMEDIATE GBX TEMP HI	DISCRETE	1 BIT	
TAIL GBX TEMP HI	DISCRETE	1 BIT	
MAIN XMSN OIL QTY LOW	DISCRETE	2 BITS	
NOSE GBX (1 & 2) OIL PRESSURE LOW	DISCRETE	2 BITS	
NOSE GBX (1 & 2) OIL TEMP HI	DISCRETE	2 BITS	
NOSE GBX (1 & 2) CHIPS	DISCRETE	2 BITS	NOTES:
MAIN XMSN OIL PRESSURE LOW	DISCRETE	2 BITS	GBX = GEAR BOX XMSN = TRAN-
MAIN XMSN OIL PRESSURE HI	DISCRETE	2 BITS	MISSION
MAIN XMSN CHIPS	DISCRETE	1 BIT	
MAIN XMSN ACCES. GBX OIL PRESSURE LOW	DISCRETE	1 BIT	
HYDRAULIC:			
PRIMARY SYSTEM PRESS.	ANALOG	1 WORD	NOTES:
UTILITY SYSTEM PRESS.	ANALOG	1 WORD	PRIMARY SYSTEM
UTILITY SYSTEM PRESS.	ANALOG	1 WORD	AND UTILITY SYSTEM
P & U OIL LOW	DISCRETE	2 BITS	P = PRIMARY
P & U PRESSURE LOW	DISCRETE	2 BITS	U = UTILITY
P & U OIL-FILTER BYPASS	DISCRETE	2 BITS	
ELECTRICAL:			
			LOCATION:
AC LOAD METER*	ANALOG	2 WORDS	TWO ENGINES
DC AMMETER*	ANALOG	2 WORDS	BATTERY LOCATION
AC GENERATOR FAIL	DISCRETE	2 BITS	POWER DISTRIBUTION

TABLE 1 (CONT)
EMMADS TYPE DATA REQUIREMENT (BASED ON YAH-64)

SYSTEM PARAMETERS	SIGNAL	DATA LENGTH	LOCATION/REMARK
ELECTRICAL: (CONT)			
RECTIFIER FAIL	DISCRETE	2 BITS	NOTES: *ALTHROUGH THESE METERS ARE DISCUSSED IN THE EDT-3 MANUAL, THEY ARE NOT SHOWN ON INSTRUMENT PANEL ILLUSTRATION IN THAT PUBLICATION OR THE OPERATOR'S MANUAL.
RECTIFIER HOT	DISCRETE	2 BITS	
BATTERY HOT	DISCRETE	1 BIT	
BATTERY CHARGER FAIL	DISCRETE	1 BIT	
EXT. POWER CONNECTED	DISCRETE	1 BIT	
ELECTRICAL SYSTEM FAIL	DISCRETE	2 BITS	
MISCELLANEOUS:			
HOT CANOPY	DISCRETE	1 BIT	NOTES: IFF = IDENTIFICATION OF FRIEND OR FOE; SAS = STABILITY AUGMENTATION SYSTEM; TADS = TARGET ACQUISTION AND DESIGNATION SYSTEM; PNVS = PILOT NIGHT VISION STATUS; ECS = ENVIRONMENTAL CONTROL SYSTEM; FCC = FLIGHT CONTROL COMPUTER
CANOPY NOT LOCKED	DISCRETE	1 BIT	
ECS MALFUNCTION	DISCRETE	1 BIT	
TAIL WHEEL UNLOCKED	DISCRETE	1 BIT	
SHAFT DRIVEN COMPRESSOR FAILURE	DISCRETE	1 BIT	
STABILATOR FAILURE	DISCRETE	1 BIT	
IR JAM STATUS	DISCRETE	1 BIT	
BLADE DE-ICE FAIL	DISCRETE	1 BIT	
MISSILE STATUS	DISCRETE	1 BIT	
VOICE CIPHER (KY-28) FAILURE	DISCRETE	1 BIT	
IFF STATUS	DISCRETE	1 BIT	
SAS STATUS	DISCRETE	1 BIT	
GUNS STATUS	DISCRETE	1 BIT	
TADS STATUS	DISCRETE	1 BIT	
PNVS STATUS	DISCRETE	1 BIT	
ROCKETS STATUS	DISCRETE	1 BIT	
FCC FAILURE (PRI BUS CONTROLLER)	DISCRETE	1 BIT	
BACKUP CONTROL SYSTEM STATUS	DISCRETE	2 BITS	
FORCE FEEL SYSTEM STATUS	DISCRETE	1 BIT	
APU:			
APU SPEED	ANALOG	1 WORD	NOTES: APU = AUXILIARY POWER UNIT; *WILL NOT BE INCLUDED IN EMMADS.
APU FAIL	DISCRETE	1 BIT	
APU ON	DISCRETE	1 BIT	
APU FIRE*	DISCRETE	1 BIT	

In summary, the message contains 23 words of parameter values and 85 packed data discretes distributed in 9 words, altogether 32 words as shown on Table 2. Also, the results from the Task I Study indicate that provision should be made for an additional 20-30 parameters required for fault analysis and performance calculations. This figure could be about 30%-40% analog and the remainder discretes. This will add another 9-14 words to the existing 32 words. Therefore, 64 data words will be specified as the EMMADS Data Requirement and used in the subsequent calculation to derive the EMMADS Data Transmission Requirement. This is to assure future growth capability (about 40-60%) to handle any additional EMMADS type parameters in the future.

2.3 EMMADS DATA TRANSMISSION REQUIREMENT

To minimize the data transmission requirements, there should be two data update rates for EMMADS. A 5-15 times per second update rate is generally sufficient for 95% of the parameters monitored by EMMADS. The other 5% such as the power turbine inlet gas temperature will require an update rate of 25-40 times per second. Therefore, for 64 data words, the EMMADS Data Transmission Requirement (in the worst case) can be stated as:

- o 4 EMMADS words are updated at 40 HZ (such as power turbine inlet gas temperature)
- o 60 EMMADS words are updated at 15 HZ

There are two methods of data transmission. dedicated end-to-end and data multiplexing as illustrated in Figure 3 (a) and (b). It should be obvious that there is no bit rate problem using the dedicated end-to-end method since the worst case, including 25% overhead for sync, parity etc, is.

Maximum required bit rate = (60 words/sample period x 15 sample periods/second + 4 words/sample period x 40 sample periods/second) x 16 bits/words x (1+25%)

= 21.2 Kilobits/second

TABLE 2
EMMADS DATA MESSAGE

DATA WORDS	
1.	Power Turbine Speed Eng. #1 (N_p1)
2.	Power Turbine speed Eng. #2 (N_p2)
3.	Gas Turbine Speed Eng. #1 (N_G1)
4.	Gas Turbine Speed Eng. #2 (N_G2)
5.	Power Turbine Inlet Gas Temperature Eng. #1 (TGT1)
6.	Power Turbine Inlet Gas Temperature Eng. #2 (TGT2)
7.	Torque Eng. #1
8.	Torque Eng. #2
9.	Oil Temperature Eng. #1
10.	Oil Temperature Eng. #2
11.	Oil Pressure Eng. #1
12.	Oil Pressure Eng. #2
13.	Engine System Packed Discretes (16)
14.	Primary Hydraulic System Pressure
15.	Utility Hydraulic System Pressure
16.	Utility Accumulator Pressure
17.	Hydraulic System Packed Discretes (6)
18.	AC Load Meter AC Bus #1
19.	AC Load Meter AC Bus #2
20.	DC Ammeter DC Bus #1
21.	DC Ammeter DC Bus #2
22.	Electrical System Packed Discretes (11)
23.	Rotor Speed (N_R)
24.	Transmission Packed Discretes #1 (16)
25.	Transmission Packed Discretes #2 (3)
26.	Fuel Quantity Tank #1 (Forward)

TABLE 2 (CONT)

EMMADS DATA MESSAGE

DATA WORDS (CONT)
27. Fuel Quantity Tank #2 (AFT)
28. Fuel System Packed Discretes (10)
29. APU Speed
30. APU Packed Discretes (3)
31. Miscellaneous Packed Discretes #1 (16)
32. Miscellaneous Packed Discretes #2 (4)

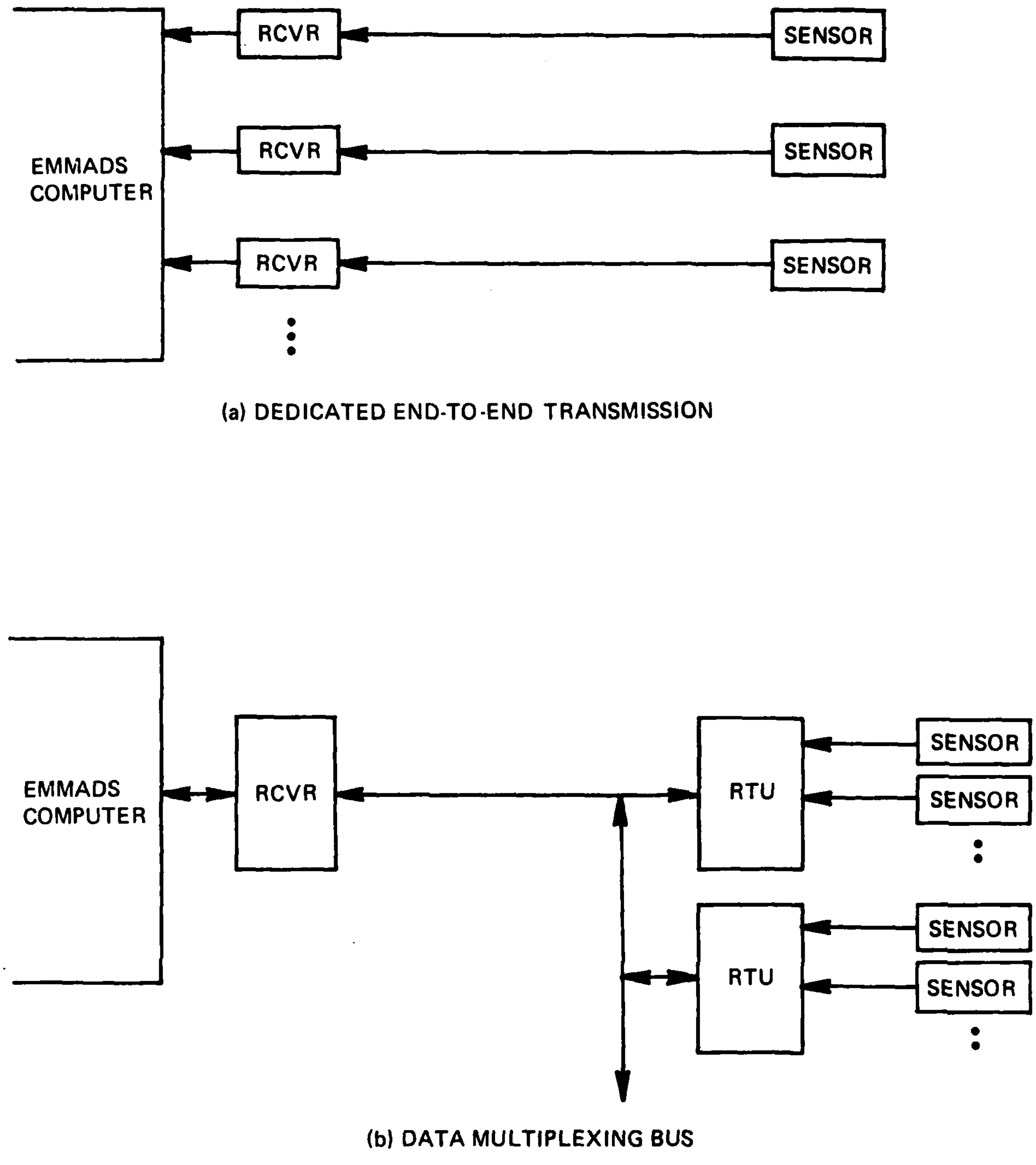

Figure 3. Data Transmission

For the data multiplexing method, a typical sequence would be:

1. The processor sends a command word to a remote data - collecting terminal requesting data.

2. After a fixed delay time, the remote terminal then returns the required N data words and a status word to the bus controller terminal.

The timing sequence is depicted in Figure 5a. For each remote terminal i, the number of data words to be sent by that terminal is N_i. For instance, YAH-64 helicopter has 13 Multiplex Remote Terminal Units (MRTU) of different sizes and shapes mounted at various locations as indicated in Figure 4. Therefore, the total number of data words, N_T, that can be collected by the EMMADS processor from these 13 MRTU's is:

$$N_T = N_1 + N_2 + \dots N_{13}$$

To determine the worst case situation, it is assumed that the EMMADS processor requires 64 raw data words as specified in Section 2-2 and that each remote terminal only transmits one word at a time. Thus, for each data word requested by the EMMADS processor, 250% overhead time (command word, a status word plus the delay time) should be added to the Transmission Requirement. The worst case bit rate can now be determined as follows:

- 4 16-bit words at 40 HZ update rate (N = 1)
- 60 16-bit words at 15 HZ update rate (N = 1)
- Multiplexing overhead = 250%
- Word Overhead (sync, parity etc.) = 25%

Maximum required bit rate = (4 words X 16 bits/word X 40/seconds + 60 words X 16 bits/word X 15/seconds) X (1 + 250%) x (1+25%)
= 74.2 Kilobits/second

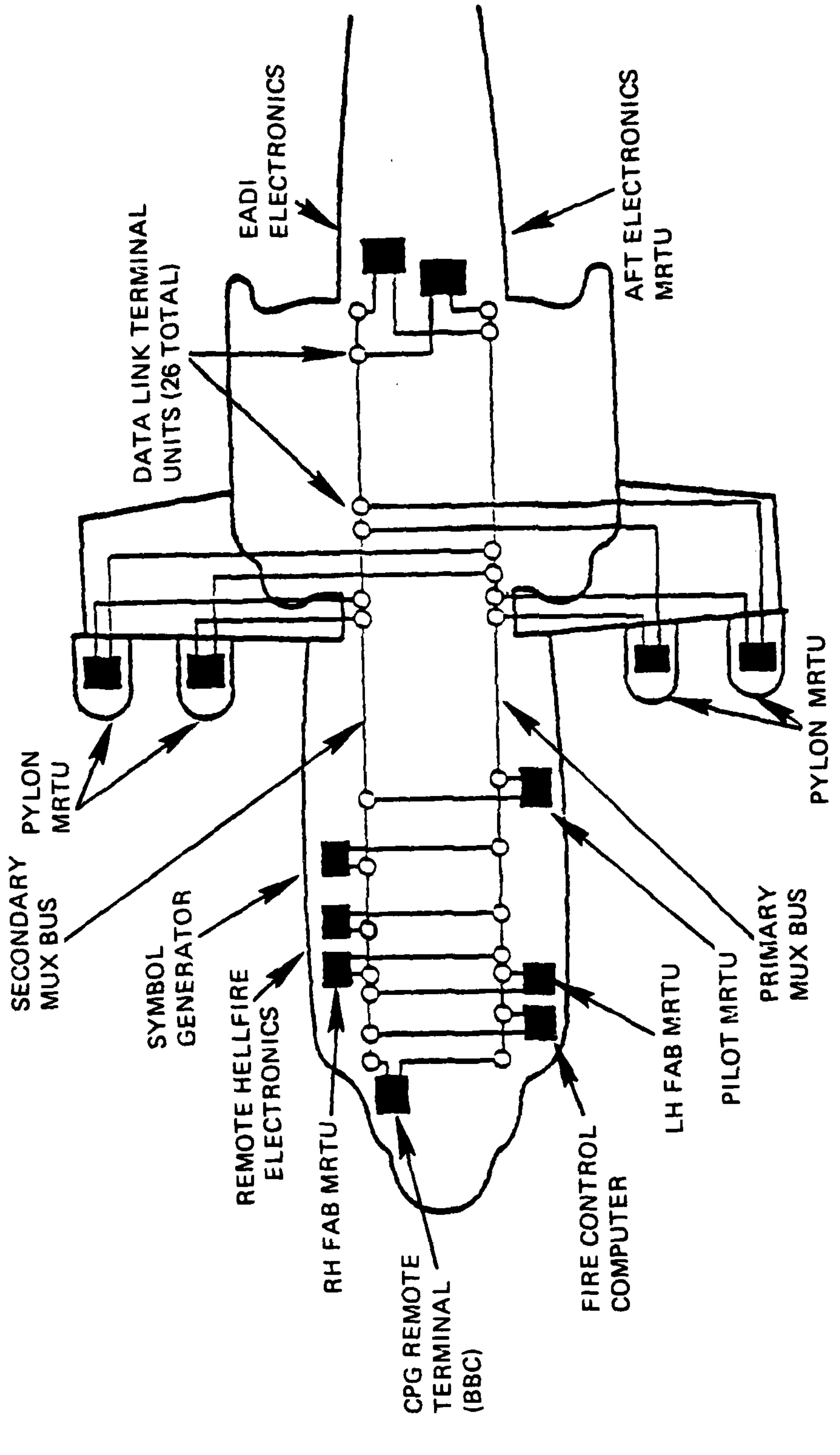

Figure 4. Multiplex System (YAH-64)

For a serial data multiplexing bus, the minimum requirement for EMMADS data transmission rate is 74.2 Kilobits per second.

The MIL-STD-1553 Bus is specified to operate at 1 MHZ data rate which is almost 14 times faster than the required EMMADS data transmission rate. Therefore, it can be concluded that 1553 Bus can handle the EMMADS data transmission requirement comfortably in the long term as well as the near term. A simple timing diagram using a 1553 Bus in an EMMADS System is illustrated in Figure 5b.

In general, there will be other uses for the RT's and the bus. As long as the required data is received anywhere within the appropriate minor frame time interval, Figure 5b is still valid.

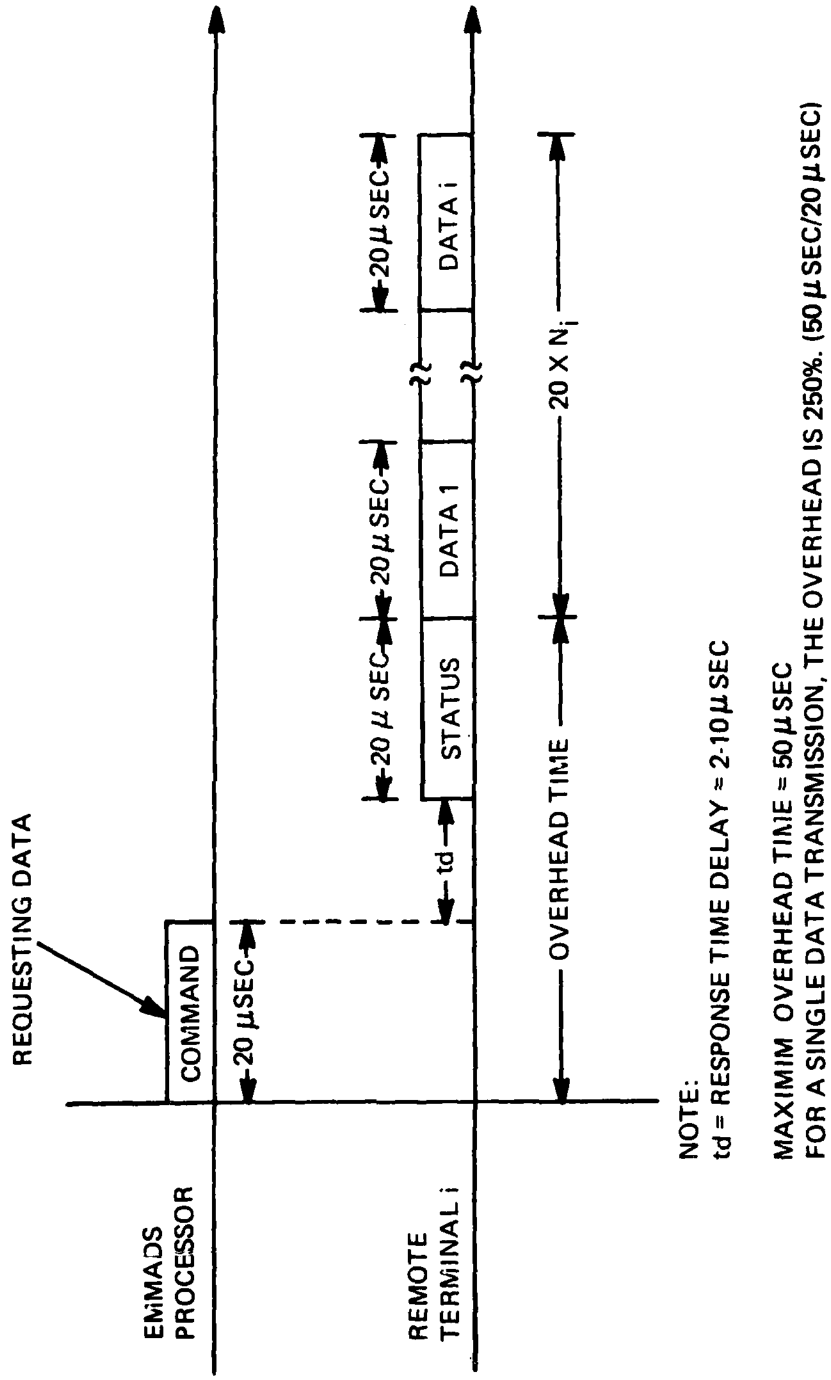

Figure 5a. Data Requesting Timing Diagram

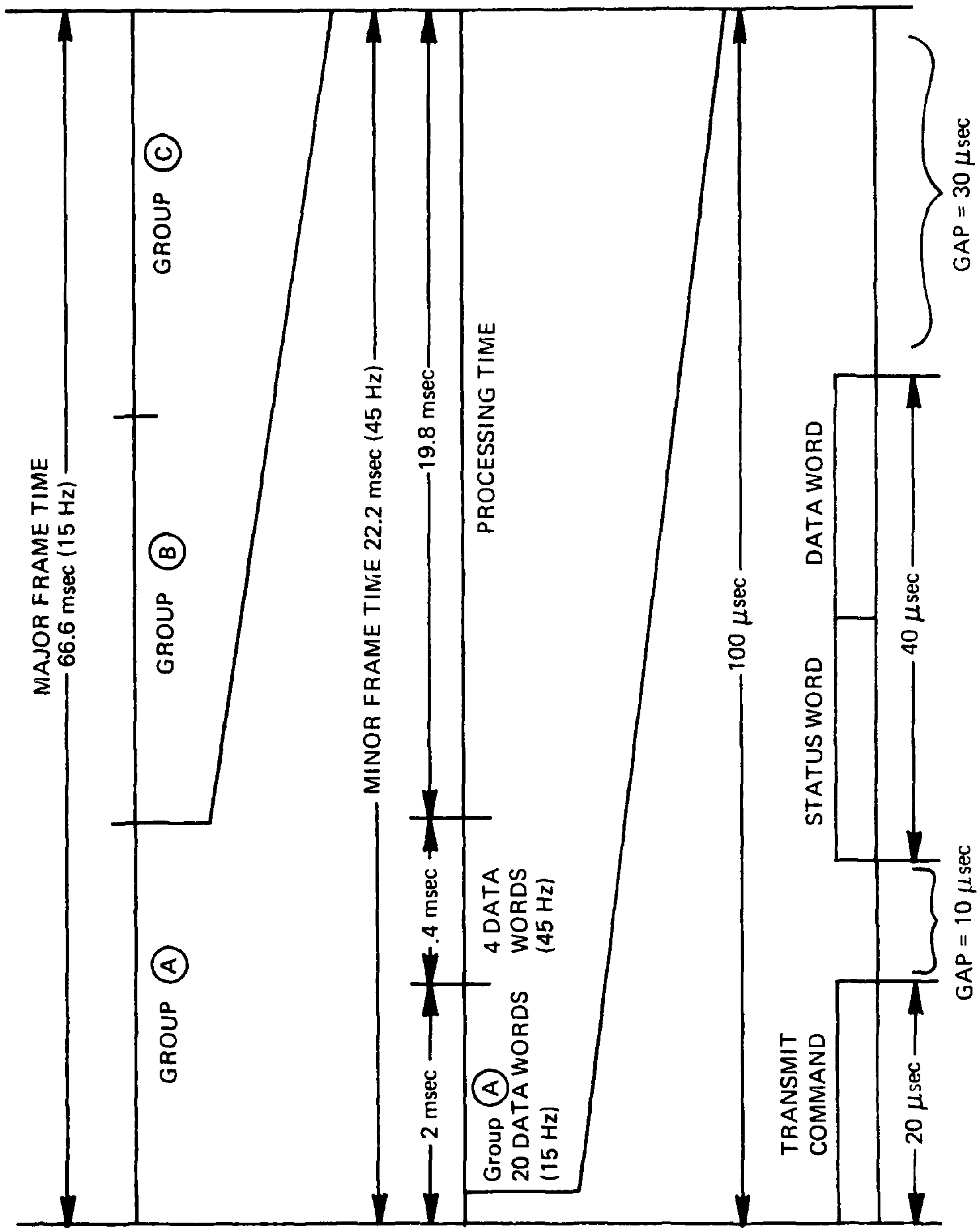

Figure 5b. 1553 Data Transmission Timing
(for the Worst Case)

Section 3
CURRENT DATA BUS SURVEY

3.1 INTRODUCTION

A survey of current standard and non-standard data buses was done on the basis of applicability to the EMMADS System. In a sense, any data bus protocol and interface which is capable of transfer 64 16-bit words from several different data remote terminals at an update rate of 15 times per second is acceptable. Since this data rate requirement is fairly easy to meet, the possible data bus candidates is almost unlimited and some subjective selection criteria must be made such as serial vs. parallel, standard vs. non-standard.

3.1.1 SERIAL VS. PARALLEL DATA BUS

A serial data bus is generally preferred as the ideal data link due to:

- Fewer lines, fewer connections
- Lower cost, especially over long distances
- Makes redundant operation practical
- Fewer I/O pins on monolithic computer
- Transmittable over telephone/radio link

However, a bit-parallel, byte serial data bus, the IEEE-488, will also be considered due to its popularity in the instrumentation industry.

3.1.2 STANDARD VS. NON-STANDARD DATA BUS

There are many strong arguments to standardize the data bus. The primary motivation is towards lower system and hardware cost. There is another equally important motivation in terms of human psychology. In brief, a standardized data bus is supposed to make life a lot easier for all of us. Just think of what life would be today if someone had not standardized lightbulbs 75 years ago. Two foreign data bus will also be mentioned briefly here. The first one is GINA developed by Electronique, Marcel Dassault, France in 1973 and the other one is Discrete Signals Data Bus System (DSDBS) by VDO Luftfartgerate, Germany in 1978.

GINA can be considered as the French military standard, the counterpart of US MIL-STD-1553. DSDBS is developed for the sole purpose of minimizing the hardware with practically zero bus control protocol. The other benefits of this approach is higher reliability and easier system testing. Papers on GINA and DSDBS were presented at the Second AFSC Multiplex Data Bus Conference on 10-12 October, 1978 at Dayton, Ohio.

3.2 AVIONICS DATA BUS STANDARDS

Modern generation aircraft are gradually utilizing the party-line-principle serial data bus for data transmission between various avionics equipment. The following data buses have been developed primarily for this purpose:

- MIL-STD-1553 (Military)
  - Aircraft Internal Time Division Multiplex Data Bus
  - Applied exclusively in the Military domain

- o ARINC-429 (Commercial)
  - Mark 33 Digital Information Transfer System (DITS)
  - A general purpose data bus used by the new generation commercial aircraft industry.

- o ARINC-453 (Commercial)
  - A very high speed data bus to meet future commercial avionics growth, such as weather radar interface bus.
  - Has identifical electrical characteristics to MIL-STD-1553.

- o ARINC-575
  - Mark 3 Sub-Sonic Air Data System (DADS)

- o ARINC-419
  - Digital Data System Compendium

All commercial buses have developed by an evolutionary process to meet the requirements of each generation of commercial aircraft. The two digital data buses defined for the new generation of aircraft are ARINC-429 and ARINC-453. ARINC-429 is evolved from ARINC-419 and ARINC-575 while ARINC-453 is developed to meet the needs of ARINC-708 Weather Radar. Since ARINC-453 has adopted MIL-STD-1553 interface characteristics, only MIL-STD-1553 and ARINC-429 will be considered as potential candidates for the EMMADS system.

3.3 GROUND EQUIPMENT DATA BUS STANDARDS

The ground equipment data bus is a highly complex subject. It consists of 4 levels of protocols with different specifications applying to different areas. These four levels are physical link, data link control, path control, and system and user control. For the EMMADS System, the first two levels of protocol will be sufficient to specifiy the required data transmission.

These standards applicable to Level I and II are listed on the Table 3.

3.4 PARALLEL DATA BUS

The major advantage of a parallel data bus is its high speed operation which, as mentioned before, is not a strong requirement for the EMMADS type system. However, the popularity of IEEE 488 in instrumentation industry has promoted our consideration due to its low interface circuit, connector, and cable costs.

IEEE-488 defines a bit-parallel, byte-serial data bus with 8 data lines, 5 interface management lines and 3 data byte transfer control lines (for handshake operation). The basic bus operates in one of two major modes at any given time; control mode or talk-listen mode. Dozens of products independently implemented by many different manufacturers have adequately demonstrated the viability of the IEEE-488 concept. It has been known that many 1553 Avionics equipments developed by different companies can not be readily connected together since each company defines their own 1553 protocol subset. This is why the easy interchange-ability and connectability of the IEEE-488 data bus is emphasized. The applicability of the IEEE-488 is further manifested in the NASA Demonstration Advanced Avionics System (DAAS) as presented in the Army Aviation Electronics Symposium on 21-23 March 1979 at Freehold, New Jersey.

TABLE 3
GROUND EQUIPMENT PROTOCOL STANDARDS

LEVEL 1: PHYSICAL LINK	
ELECTRICAL:	
EIA-RS-232C/MIL-STD-188C	INTERFACE STANDARD FOR DATA TERMINALS
EIA-RS-422/FEDERAL-STD-1020	ELECTRICAL STANDARD FOR INTERFACING BALANCED CIRCUITS
EIA-RS-423/FEDERAL-STD-1030	ELECTRICAL STANDARD FOR INTERFACING UNBALANCED CIRCUITS
CCITT V.35	48-KBIT/SEC DATA-TRANSMISSION STANDARD
MECHANICAL:	
EIA-RS-232C	MECHANICAL STANDARD FOR DATA TERMINAL INTERFACE CONNECTOR
EIA-RS-449	MECHANICAL STANDARD FOR CONNECTOR PIN ASSIGNMENT
LEVEL 2: DATA-LINK CONTROL	
BIT-ORIENTED	
SDLC (IBM)	SYNCHRONOUS DATA-LINK CONTROL
ADCCP (ANSI)	ADVANCED DATA-COMMUNICATIONS CONTROL PROCEDURE
HDLC (ISO)	HIGH-LEVEL DATA-LINK CONTROL
CHARACTER-CONTROLLED	
BISYNC (IBM)	BINARY SYNCHRONOUS COMMUNICATION
ANSI-X3.28	CHARACTER-CODE CONTROL STANDARD
ISO-1745	BASIC-MODE CONTROL STANDARD
CHARACTER-COUNT	
DDCMP (DEC)	DIGITAL DATA-COMMUNICATION MESSAGE PROTOCOL

3.5 SUMMARY

A comparison of bus's characteristics is presented on Table 4. The four most promising standards are MIL-STD-1553, ARINC 429, RS-232C (RS-423) and IEEE-488 due to their performance specifications and their wide acceptances. These four standards and dedicated hardwired data lines will be evaluated and compared in the next section.

The two foreign buses, GINA and DSDBS, although equally attractive, will not be considered here due to several factors. (1) Both buses do not appear to offer any significant advantages. (2) Both buses do not have wide acceptances and both countries are working to make their bus compatible with the 1553. (3) United Kingdom has decided to adapt the 1553 as their military standard. (4) Unless an agreement is been made, it is difficult to develop a foreign bus protocol without any further information and resource.

Currently, the most energetic commercial efforts are concentrated on several standards such as ETHERNET (XEROX) aimed for packet switching in a network processing system. The EMMADS system is inherently a centralized system and will not be benefitted in any significant way from results of such efforts.

TABLE 4
BUS CHARACTERISTICS

BUS	MIL-STD 1553	ARINC 429	RS232C (RS423)	GINA (FRENCH)	DSDBS (W. GERMANY)	IEEE 488
Type	Serial	Serial	Serial	Serial	Serial	Parallel
Data Bits/Word (Total Bits)	16 (20)	19 (32)	5-8 (10)	8 (10)	1	8
Transfer Rate	1 MHZ	12.5 KHZ OR 100 KHZ	20 KHZ (300 KHZ)	1 MHZ	256 KHZ	1 MHZ
Data Format	Manchester	Bi Phase Binary (NRZ)	Bi Phase Binary (NRZ)	Bi Phase Manchester (RZ)	Manchester (RZ)	Binary
No of Lines	2 (Twisted)	2 (Twisted)	3-10 (2 data, 8 control)	2 (1 data, 1 procedure)	2 (1 data, 1 power)	16 (8 data, 8 control)
Sync	Sync Pulse	Self Clocking	Handshake (2 lines)	Self Clocking	Sync Pulse	Handshake (3 lines)
Max Devices (Secondary Devices)	32	256	1	32 (1024)	256	31 (961)
Data Identification	Subaddress & Count	Label	None	Subaddress & Count	Sequencing	None
Data Validation	Parity & Format	Parity & Format	Parity & Format	Parity	Bus Monitor	None
Control Method	Command Response	None	None	Command Word	None	Bus Management Lines
Max Word Rate (word/sec)	50K (16 bits/ word)	3K (19 bits/ word)	2K (30K) (8 bits/ word)	100K (8 bits/ word)	32K (8 bits/ word)	500K (8 bits/ word)

NRZ - NOT-RETURN-TO-ZERO
RZ - RETURN-TO-ZERO

Section 4
TRADEOFF STUDY

4.1 INTRODUCTION

4.1.1 TRANSMISSION METHODS

The gathering of data information for the EMMADS System can be realized in four different ways (See Figure 6).

1. Direct Link - a direct line for each sensor (analog and discrete)

2. Dedicated Bus Link - a dedicated bus for each remote terminal (RT). No bus controller is required. (ARINC-429, RS-232C)

3. Multiplex Bus Link - a common bus shared by every RT coordinated by a bus controller (IEEE-488, MIL-STD-1553)

4. Hybrid Link - Any combination of (1), (2), & (3)

The current sensor data informations on CH-47, UH-60, and OH-58 helicopters are sent via the Direct Link method (Method 1). On YAH-64 helicopter, data from various sensors or subsystems are concentrated at MUX Remote Terminal Units (MRTU) and then transmitted on a 1553 MUX data bus (Method 3). However, most of the sensor data required by EMMADS is not currently on that bus.

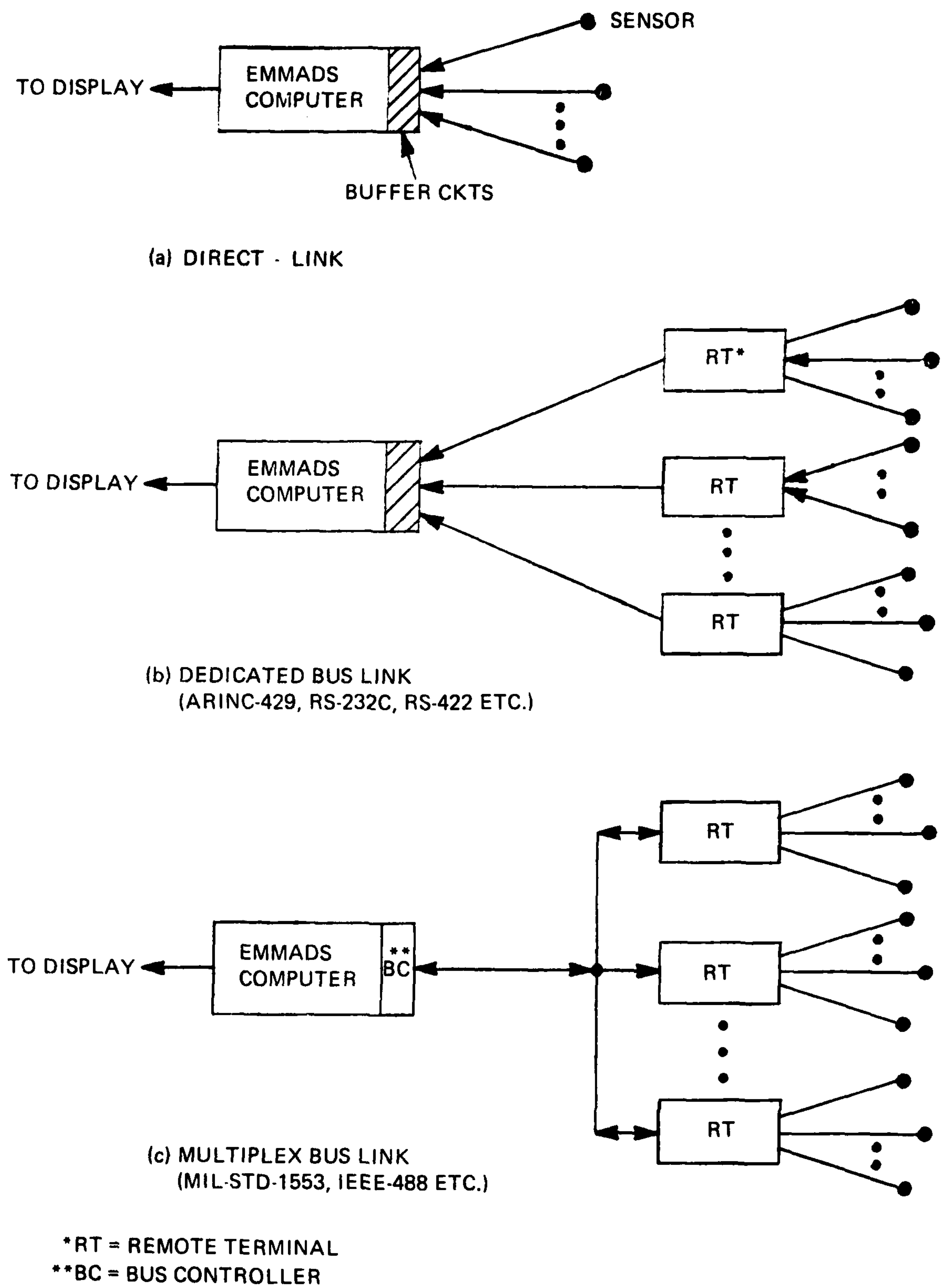

Figure 6. EMMADS Data Transmission System

4.1.2 SYSTEM CONFIGURATION

The tradeoff study of various data bus standards and transmission link methods is based on the following system configuration:

- EMMADS as a stand-alone system

In practice, EMMADS data collecting function can be integrated into an already existing data bus structure, for example, the 1553 MUX bus on the YAH-64 helicopter. This can eliminate some duplicated hardware and software. Since 1553 MUX bus has been developed as the military aircraft standard, it is expected that, in the future, 1553 MUX bus will be available on almost all the military aircrafts. This certainly will make the 1553 MUX Bus a more attractive bus candidate than other bus methods. However, EMMADS will be treated as a stand alone system here.

- EMMADS as a centralized system

The fact that EMMADS collecting data from many sensors located at various parts of an aircraft and concentrating these data at the EMMADS Processor indicates that inherently EMMADS has a highly centralized system architecture characteristics. This does not imply that EMMADS concept cannot be implemented in a distributed processing manner. However, since data from various sensors is collected for limit checking and ultimate display on a display unit, the distributed processing is not appropriate. As long as EMMADS acts as a stand alone system (assumption 1), EMMADS should be a centralized system.

- Single transmission link method approach is applied to EMMADS

To retrofit EMMADS into the existing aircrafts, the hybrid link, e.g. that some data are sent by direct wires while others are sent via a data bus probably is the most cost effective system. However, in an effort to determine the best transmission method, only the first three methods, direct link, dedicated bus link and MUX bus link, are evaluated and compared for the EMMADS System. A hybrid link would be appropriate for a partial retrofit only.

4.2 SOME SELECTED TRANSMISSION PARAMETERS EVALUATION

Some selected parameters such as data rate, cable length, number of drivers/receivers, and number of wires for each transmission method is presented on Table 5.

The following observations can be made from Table 5:

1. The maximum cable length for IEEE-488 and RS-232C is specified to be 20 meters (65.6 feet). The dimensions of the CH-47 helicopter, excluding the rotor blades, are approximately 51 feet long, 17 feet tall and 12 feet wide. Therefore, the cable length of these two buses is a potential limiting factor for their application on the big aircraft. The newer RS-422 is similar to RS-232C and is useable for longer cable lengths.

2. The number of line drivers is an important parameter since this is where most of the power is dissipated. In terms of minimum number of line drivers (LD)/line receivers (LR) and the minimum number of interface components (IC) required to implement them, Table 5 shows that MIL-STD-1553 Bus require fewest LD/LR's and fewest IC's. ARINC-429 is rated the second best in this respect.

TABLE 5
A COMPARISON OF DATA BUS BY SELECTED PARAMETERS

STANDARD	LINK	TRANSFER RATE	MAX WORD RATE	CABLE LENGTH	MINIMUM # OF DRIVER # OF RECEIVER	MINIMUM NUMBER OF IC'S REQ'D N=6, M=30	# OF WIRES # OF CABLES N=6, M=30	# OF WIRES # OF CABLES N=15, M=100
MIL-STD-1553	MUX-BUS	1 Mbit/s.	50K (16 bits/word)	300 ft.	LD: N+1 LR: N+1	N+1 (7)	2 wires	2 wires
IEEE-488 (GPIB)	MUX-BUS	1 Mbyte/s.	500K (8 bits/word)	20 meter	LD: 16(N+1) LR: 16(N+1)	2(N+1) (14)	16 cables	16 cables
ARINC-429	DEDICATED BUS	100 Kbit/s	3K (19 bits/word)	300 ft.	LD: N+1 LR: 2N	N+N/2 (9)	14 wires	32 wires
RS-423	DEDICATED BUS	300 Kbit/s (Max)	30K (8 bits/word)	2,000 ft.	LD: 2N LR: 2N	2N+2(N/4) (16)	12 cables	30 cables
RS-232C	DEDICATED BUS	200 Kbit/s (Max)	2K (8 bits/word)	20 meter	LD: 2N LR: 2N	2N+2(N/4) (16)	12 cables	30 cables
HARDWIRED	DIRECT	ANALOG/ DIRECT	ANALOG/ DIRECT	300 ft.	LD: M LR: M	M+M/2 (90)	60 wires	200 wires

NOTE: N = Number of remote terminals (RT), 4 N 15
M = Number of Data Sensors, 30 M 100
IC = Interface components
Number of IC's is determined from # of drivers (LD)/# of Receivers (LR) Only.
It does not take into account the hardware required for XMTR/RCVR Control,
Bus Control and other buffers.

3. The most important entry on Table 5 is the number of transmission wires required for each data transmission method.

   Let N = Number of remove terminals (RT)
   M = Number of data sensors

   The typical value for N is between 4 and 15 and M is between 35 and 100. The second last column, with N=6 and M=30, shows that 1553 MUX Bus has a significant advantage over all other buses. The advantage is even more dramatic in favor of 1553 Bus in the last column where N=15 and M=100.

4.3 HARDWARE CONSIDERATION

4.3.1 SIGNAL CONDITIONING

For the direct link method, each sensor is wired directly to the EMMADS Processor where the analog signal is scaled/normalized and then converted to digital form to be processed. On the other hand, using the data bus link methods, sensors are grouped and wired directly to their respective RT's. Each RT will condition, filter, multiplex, scale/normalize and convert to digital signal from raw sensor information before the data is transmitted to the EMMADS Processor. In any case, some form of signal conditioning is required in order to accept a wide variety of signal types such as discrete (5VDC, 28VDC), AC analog, DC analog, synchro, switch closure, tachometer torquer, frequency, and thermocouple etc.

Signal conditioning function needs to be realized and implemented for the data bus link more so than the direct link method. However, there are several vendors offer off-the-shelf the signal conditioner and 1553 remote terminal in one unit.

4.3.2 BUS TRANSMISSION HARDWARE

A typical data bus system includes a bus controller, interface controllers, line drivers and line receivers, as illustrated in Figure 7.

For the dedicated bus link method, no bus controller is really necessary. It should be realized that the design for any bus controller or interface controller was a quite involved task in the past using discrete components.

With so many IC's (integrated circuits) currently available on the market as listed on Table 6, not only is the hardware design task simplified but they also reduce the size and weight of each remote terminal (RT) quite significantly. When newer and more powerful LSI (large scale integration) IC's, such as BIU #2 by Harris, is applied, the hardware burden of RT will be getting smaller and eventually will make the bus type method far superior to the direct hardware method.

In the future, it can be expected that sensor "systems" will be developed which will partially integrate the sensor and bus interface into a compatible system.

4.3.3 HARDWARE SIZE AND WEIGHT

The primary motivation of utilizing a data bus is to reduce both the numbers of cables and connectors and the complexity of interconnection problem. It has already been shown that a 1553 Data Bus requires only a twist pair of wires instead of the 60-200 wires for the direct link method. The next concern is whether the added size and weight of 1553 Bus terminals is justifiable with respect to these cables to be eliminated.

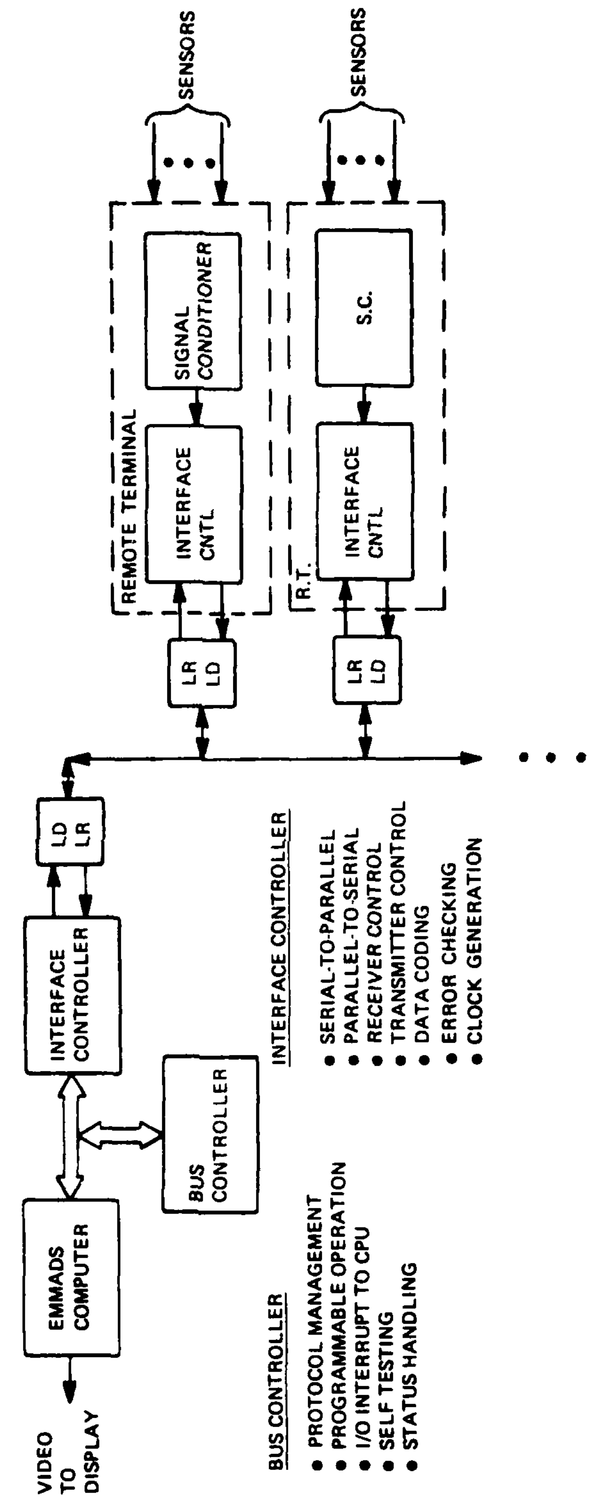

Figure 7. A Typical Data Bus System (Bus Controller, Interface Controller, Line Driver/Line RCVR)

TABLE 6
SOME CURRENT BUS INTERFACE IC (4/80)

STANDARDS/ PROTOCOLS	BUS CONTROLLER	TXMIT/RCVR INTERFACE CONTROL	LINE DRIVER (LD) LINE RCVR (LR)	OTHER
MIL-STD-1553	HARRIS BIU #1 HARRIS BIU #2 (available in 1Q/81) CTI-Intelligent Terminal (available in 1Q/81)	SMC-COM 1553 "SMART" MANCHESTER ENCODER/DECODER HARRIS-15530 HARRIS-15531	CTI - 1231 DDC - 8553	TRANSFORMER
ARINC-429	-	HARRIS HS-3282 (GE ARINC-429 Chip)	Harris ( ) (LH0002 OP AMP)	
IEEE-488	INTEL-8292 TI-TMS 9914	INTEL-8291 FAIRCHILD 96LS488 MOTOROLA-MC68488 SIGNETICS-HEF4738	INTEL-8293 AMD-AM3448 MOTOROLA-MC3448	INTEL-8257 DMA
ADCCP, SDLC/HDLC, BISYNC, DDCMP	INTEL-8273 SIGNETICS-2652 SMC-5025 FAIRCHILD-3846/6856 MOTOROLA-6854 WESTERN DIGITAL-1933 ZILOG-SIØ TI-TMS9903	USART INTEL-8251 SIGNETICS-2651 -2661 INTERSIL-IM6402 TI-TMS5501 USRT/UART MOTOROLA 6852/6850 AMI-235- SMC-COM 2601 NEC-UPD 379 NSC-8250 HARRIS-6402/3	RS-232C(MIL-188C) AMD-AM 9616/9617 AMD-AM 2616/2617 RS-422(FED-STD-1020) AM26LS31/32 RS-423(FED-STD-1030) AM26LS29/30/32 (and other equivalent devices)	

Since the total cable size/weight information is not readily available, the cable size/weight of CH-47C instrumentation and caution/warning panel lights will be estimated here and later compared with a 1553 Data Bus.

From the wiring diagram of CH-47C found in TM 55-1520-227-23-5, it is determined that there are:

63 cables @ 65 ft.	=	4,095 ft.
22 cables @ 30 ft.	=	660 ft.
4 cables @ 40 ft.	=	160 ft.
1 cable @ 12 ft.	=	12 ft.
Other misc. cables	=	895 ft.

Total estimated cable length = 5,852 ft.

Assume all cables used on CH-47C are size #20 copper wire with:

Weight density = 5.43 lb./1,000 ft.
Cable diameter = 0.058 inch

Therefore:

Est. Cable size = $(0.029)^2$ x   x 5852 x 12 = 185.43 in^3
Est. Cable weight = 5.43 lb. x 5.852 = 31.78 lb.

To replace these cables, let us assume that one bus controller and six RT's are needed. With the current LSI technology, it is possible to design a bus controller on one multilayer board (MLB)

and a remote terminal (including signal conditioner) on 2 MLB's. The size of a MLB is 33.25 cubic inches and its weight is about 1 lb. (9-1/2" x 7" x 1/2"). For a typical bus structure:

New Design		Current Data From Conrac Corp.
Size		
1 controller @ 33.25 in^3	= 33.25 in^3	3 SACT's @ 789 in^3 each
6 RT's @ 66.5 in^3	= 399. in^3	
500 ft. cable (include the sensor to RT and RT to BC wiring)	= 15.85 in^3	
Est. total size	= 448.1 in^3	2,367 in^3
Weight		
1 controller @ 1 lb.	= 1 lb.	3 SACT's @ 16 lb. each (production)
6 RT's @ 2 lb.	= 12 lb.	
500 ft. cable	= 2.71 lb.	
6 power supplies @ 1-1/2 lb.	= 9 lb.	
6 chassis @ 1-3/4 lb.	= 10.5 lb.	
Est. total weight	≈ 35.21 lb.	48 lb.

Based on these rudimentary estimations, it seems that with the new design, the weight remains about the same while the size will increase. The increase in size is certainly quite acceptable (262.5 in^3) for the CH-47 helicopters.

4.4 BUS LOADING

There are two issues in regard to the bus loading. First, the required data must be transmitted or received within a specified

time frame. This requirement determines the minimum data rate requirement for the data bus employed. Second, if the bus controller function is implemented by software, the software program must be executed and completed within the same given time constraint as before. When the EMMADS acts as a stand-alone centralized system, both issues will not present any bus loading problem since the transmission requirement for the EMMADS system is fairly low. The data transmission rate determined for the EMMADS is about 74.2 kilobits/second. This represents 7.42% of bus loading time on a 1MHZ data bus. A 1553 Bus Controller designed by General Electric using Signetics 8x300 microprocessor has a constant 250 nsec instruction time. The controller software size is about 1 kiloword. This makes the bus transmit/receive operation transparent to the EMMADS processor after the power-on initialization. Therefore, the bus loading is really not a concern here for a stand-alone EMMADS system. However, in case the bus controller is embedded in the host computer software and bus control allocation technique is needed, such as on the YAH-64, then the data transmission can be a system/software problem.

4.5 NOISE IMMUNITY CONSIDERATION

In order to reduce noise problems, analog signals have to be carefully shielded, grounded, terminated, matched etc. It is well known that digital signals offer much better noise immunity than the analog signals. In other words, to increase noise immunity, the Analog-to-Digital converter should be placed close to the sensor sources. Upon the completion of A/D conversion process, the digital data is transmitted on the digital bus lines. Therefore, from noise immunity standpoint, there is a significant advantage to the use of a digital data bus.

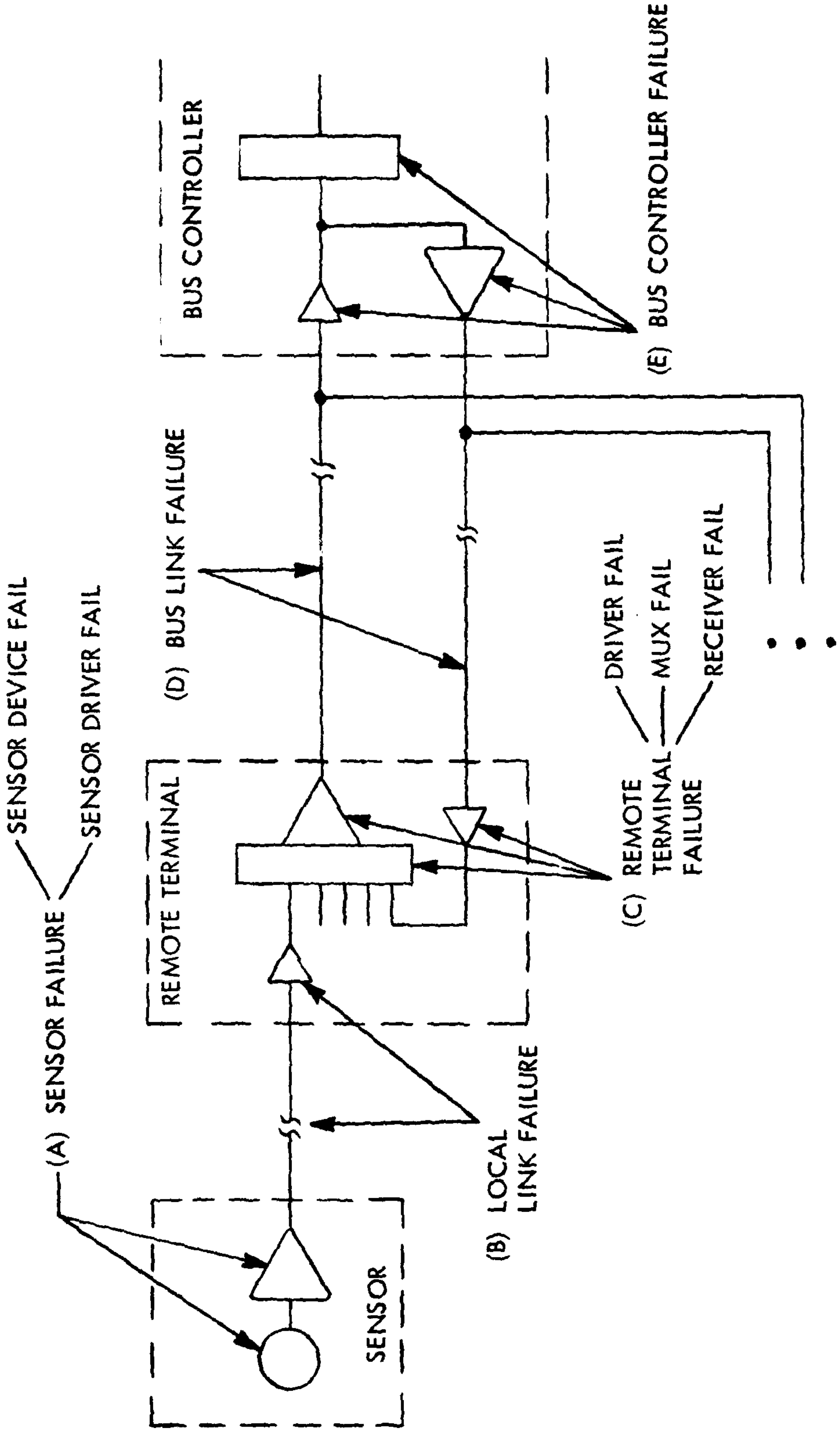

Figure 8. Single Point Failure Modes

4.6 SINGLE POINT FAILURE MODES AND EFFECTS

A multiplex bus exhibits five basic single point failure modes as illustrated in Figure 8.

a. sensor failure
b. local link failure (between sensor and RT)
c. RT failure
d. bus link failure (between RT and Bus Controller)
e. Bus Controller failure

It is quite easy to conclude that (a) and (b) produce a single parameter error, (c) and (d) cause error on several parameters that share the same RT, and (e) means total loss of the system. It should be mentioned that the bus controller can check each RT and upon determining that it is not functioning properly, the self test or time-out circuits can automatically "shut-down" the particular RT which is bad by disabling the RT's transmitter.

A solution to reduce the failure rate and its effects is to add a redundancy with switch-over capability at the RT as illustrated in Figure 9. This dual redundancy seems to represent the best trade-off between low failure rate and low system cost. The idea is that once the main channel has failed and switched to the standby channel, it has a very high probability to remain operational until the mission is completed. Once the aircraft returns to the ground base, the equipment can be repaired and restored to the original dual redundancy configuration again. The high cost of triple redundancy bus system does not seem warrant its application.

Each single point failure in a direct link system will lose only a single parameter. Due to large numbers of cables and connectors, redundancy is not a very practical scheme to improve the failure rate. One might add redundancy only to these critical parameters to reduce the wire count.

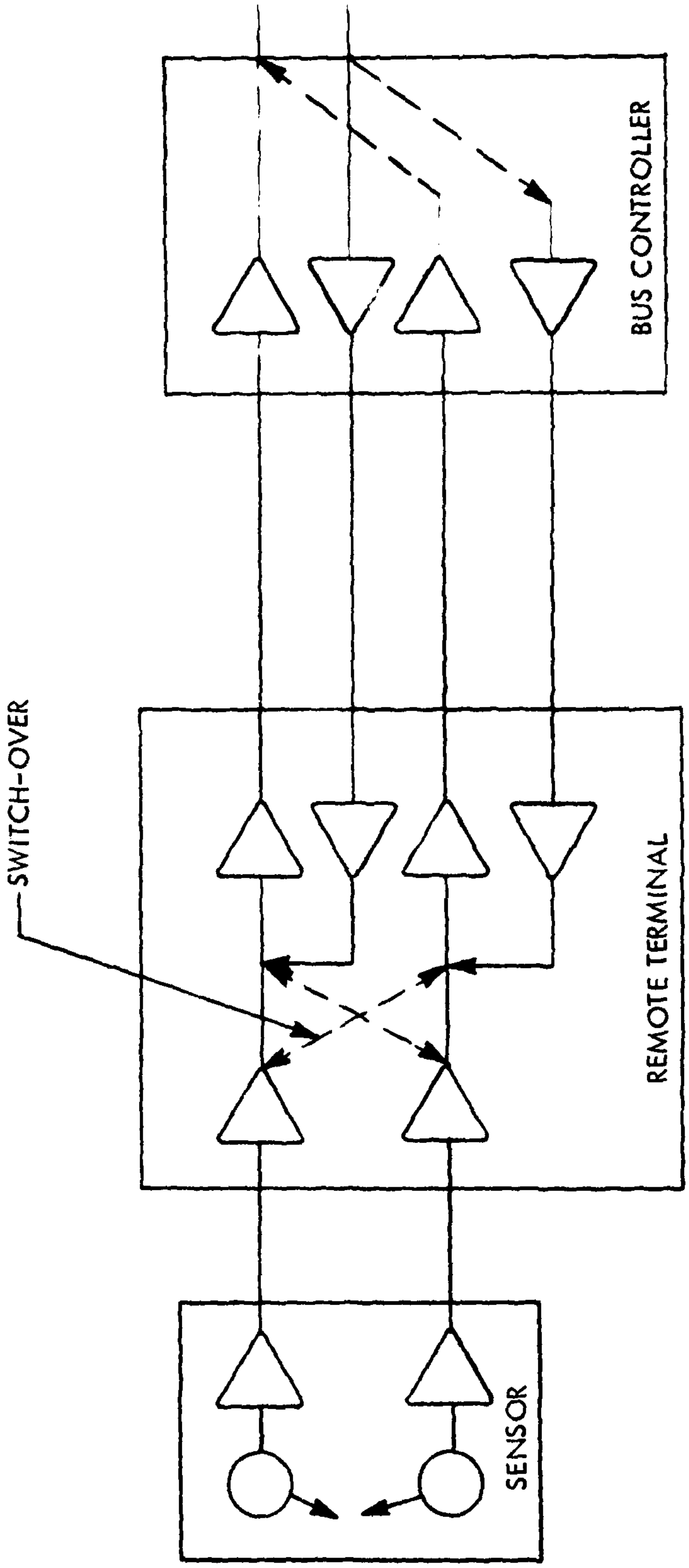

Figure 9. A Dual Redundancy Bus System

Section 5
APPLICATION OF OPTICAL FIBERS AS COMMUNICATION MEDIA

5.1 INTRODUCTION

With the increasing demand and popularity of the fiber optic system, coupled with steadily improved performance and decreasing cost, it has become an extremely attactive candidate as the communication media.

In general, the design of a fiber optic communication system, like other communication systems, is determined and based upon four basic user requirements.

- o The desired data rate (bandwidth)
- o The bit error rate (signal-to-noise ratio)
- o The distance between terminals (or end-devices)
- o The type of source information (digital or analog)

Once the basic requirements are established, a designer must also consider numerous other factors such as weight, size, cost, reliability, power consumption, environmental conditions etc. Many of these factors are interrelated and the design of an optical system can be rather complex if all cases were to be considered.

A simplified fiber optic communication system is shown in Figure 10. It consists of optical driver, light source (LED or Laser), optical fiber cables, connectors, couplers, photo detector (APD or PIN diode), receiver and repeaters (if needed). One major task for designer is to select the proper components from a wide variety of manufacturers to meet the system requirements and its

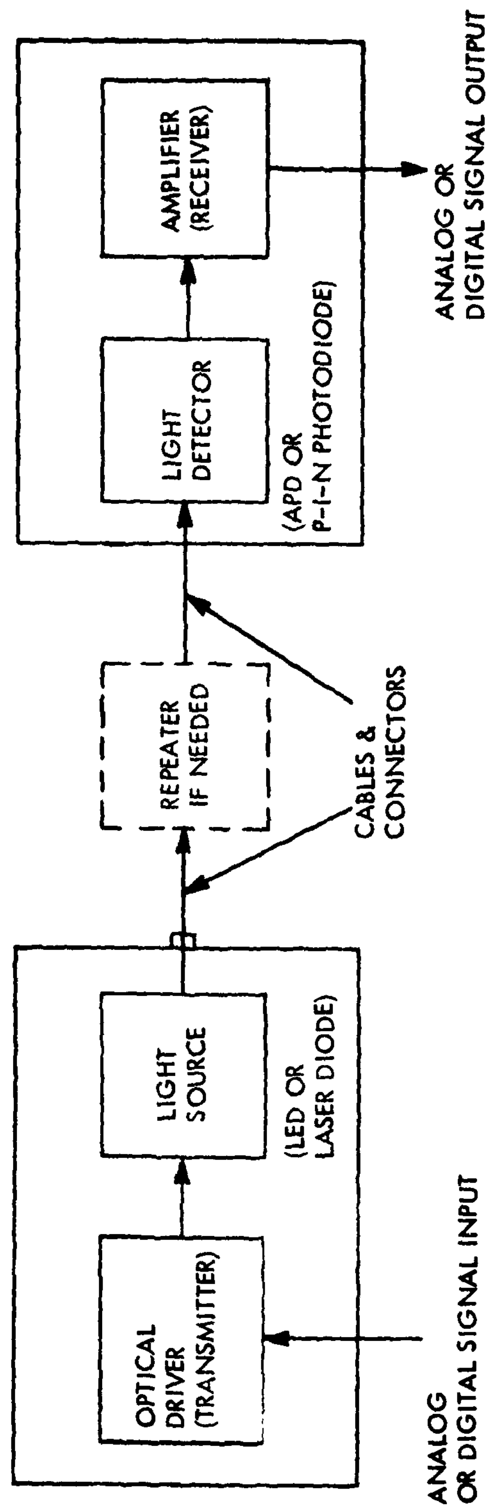

Figure 10. A Simplified Optic Communication System

constraints. This is particularly important since fiber-optics is a rapidly changing technology and new, improved products (fibers, connectors, couplers, diodes etc.) are constantly been introduced to the market.

5.2 BENEFITS OF OPTICAL FIBER TRANSMISSION LINE

There are several major advantages to implementing the optical fiber transmission line into the EMMADS system.

- Optical transmission is immune to any ambient electrical noise, ringing or electromagnetic interference (EMI).

- The size and weight of optical fiber cable is much less than the conventional cable or coaxial cable.

- Optical cables are safe to use in explosive environments and eliminate the hazards of short-circuits in metal wires and cables. Optical systems can be ma to have total electrical isolation.

- Optical cable has quite low attenuation (i.g. 7db/km for Times glass fiber SAI-55-90) and long critical length (i.g. 10 km for Corning silica fiber 1156-7).

The most important advantage of fiber optics transmission line is in the increased bandwidth. It is possible for a designer to use fiber optic's additional bandwidth to increase system capabilities and/or simplify system integration. Some implications of a wideband bus are:

1. Increased interprocessor communications.
2. Allow the use of message formats and protocols which are highly fault-tolerant.

3. Additional data can be placed on the data bus both during original design and in subsequent retrofits.
4. Bus traffic management can be simplified.
5. Transaction time can be reduced.

An illustrative comparsion of properties of fiber-optics transmission versus properties of coax and twisted pair transmission is shown in Table 7. One should notice that with the current technology, a fiber optic cable link can be quite costly when factors such as environmentally sound cable cladding and jacketing, and installation labor are factored in.

5.3 POTENTIAL PROBLEMS WITH FIBER OPTIC TRANSMISSION LINE

The primary technological barrier to use of fiber optics in a data bus is the losses associated with data bus "T" or STAR couplers. Once the fiber optic cable link meets the MIL requirement, there are still practical difficulties in using fiber optics. For example, such difficulty may arise at the cable interface area. The optic cable must have a flat end without any contamination during installation, maintenance, and full service life to ensure the total signal loss is still within system spec. Most fibers are thin and fragile with small coupling areas. Unlike coaxial cable, when optical cable is vandalized, cut or in any other way damaged, the signal loss presents a much more serious problem. When the fiber cable breaks, it is difficult to replace since the cable cannot be fixed and reconnected easily. Sometimes installing a new cable seems to be the only alternative. This requires sufficient spare parts to be ready at all field locations at all times. Without any cable standardization among different vendors, the spare parts problem can be very expensive and troublesome if several different sizes, shapes and fiber materials are installed for different helicopters.

TABLE 7

PROPERTIES OF DATA TRANSMISSION CABLES

	Fiber Optics	Coax	Twisted Pair
Low Cost	X		X
Temperature to 300°C	X	X	X
Vibration Tolerant	X	X	X
Low Cross Talk	X	X	
No Cross Talk	X		
EMI Noise Immunity	X		
Total Electrical Isolation	X		
No Spark/Fire Hazards	X		
No Short-Circuit Loading	X		
No Ringing/Echoes	X		
EMP Immunity	X		
Temperature to 1000°C	X		
Weight Savings	X		
Decreased Size	X		
Bandwidth Capability (300 meters)	200 MHz	20 MHz	1 MHz

Source: "An Advanced SSM Designed to reduce crew workload during the monitoring of Helicopter Subsystems" by J McGee, H. Harper, USAAVRADCOM-TR, March 1980

5.4 CONCLUSION AND RECOMMENDATION

It is without any doubt that eventually all major communication link between various military subsystems and fixed stations will be via the optical cables. This is particularly true for avionics equipment due to the small size, light weight, enhanced security, absence of crosstalk and immunity of EMI and jamming interference. Specific recommendations on fiber optic link are:

- o Leadership - U.S. Government should provide the leadership to standardize the fiber optic system specs, cables, and connector etc.

- o Cable protection - the cable must be rugged enough to withstand the rough treatment from the equipment maintenance personnel.

- o Training - field maintenance personnel must be trained in the proper way to handle the avionics equipment, especially these optical fiber cables.

As indicated here, the potential benefits of an optical data bus for the EMMADS System are many while the disadvantages are mostly in the area of field maintenance, not in the development stage.

In the long term, the fiber optical bus link would provide the best performance and most cost effective system.

Section 6
EMI CONSIDERATION

The survivability of modern aircrafts is increasingly dependent upon all the avionics equipments on the aircraft. Consequently, it is essential that these avionics equipments will remain operational either during or after the presence of a strong external electromagnetic interference (EMI). External EMI may be generated either by natural phenomena, i.g. lightning, or by artificial means, such as nuclear explosion.

The applicable EMI requirement document is the MIL-STD-461, Electromagnetic Interference characteristics, Requirement for Equipment, which should be complied by all avionics equipments including the EMMADS type system. To ensure compliance with MIL-STD-461, some kind of interference rejection techniques must be designed and implemented. Typical electrical and mechanical techniques are grounding, shielding, filtering and component selection.

The EMMADS analog signals are in the low frequency region. For low frequency analog signals, filtering techniques are quite effective. For example, the use of filter-pins or small capacitors at the cable connector in the past have demonstrated a good result. Filtering technique becomes unacceptable when the input signal is a high speed, square wave digital signal. One alternative is to have a good shielding on the cable. As mentioned in Section 5, the use of optical fiber as the communication media is another method to eliminate the EMI problem.

Once the EMI threat is defined and specified, interference rejection techniques designed and implemented for a particular avionics system, such as EMMADS, EMI tests and procedures must be performed to demonstrate the equipment's low susceptibility to EMI. The equipment should be subjected to tests with methods in accordance with MIL-STD-462, Electromagnetic Interference Characteristics, Measurements of. A typical testing frequency range is between 20KHZ - 40GHZ with peak field intensity between 20 volts/meter to 200 volts/meter. Past experience has indicated that EMI should not be a serious problem for a 1 MHZ data bus with proper interference rejection techniques.

Section 7
CONCLUSION AND RECOMMENDATION

The results of Section 4 can be summarized in eight areas as listed in Table 8.

Multiplexed data transmission (MUX Bus) does offer the following additional advantages:

- o Reduce EMI: fewer and shorter wires mean less EMI pickups.
- o Enhanced testability: Bus Controller can continuously check each remote terminal and report any fail status on display.
- o Improved transmission accuracy: data can be re-sent, immediately in the case of noise induced data errors.
- o Increased flexibility: software change to arrive at the optimal performance and adapt to any changing requirement.

As might be expected, the MIL-STD-1553 dual redundancy data multiplexing bus offers the best data transmission method for the EMMADS system. This is not coincidental since the 1553 bus is designed specifically for the avionics application with signals bandwidth less than 400 Hz. (The maximum EMMAD signal bandwidth is 40 Hz, see Section 2-3). When several specialized LSI IC's designed for the 1553 bus becomes available, it means that the cost, size and weight of 1553 bus hardware will continue to decrease.

TABLE 8

SUMMARY OF TRANSMISSION STUDY

#	ITEM	RESULTS
1	Cable Requirements	MUX Bus requires the fewest cables
2	Components (line Drivers/line Receivers)	MUX Bus requires the fewest LD/LR
3	Signal Conditioning	All three methods require some signal conditioning
4	Available LSI Supports	Many LSI IC's are available to handle data bus protocol and simplify the MUX Bus design
5	Weight & Size	Weight remains about the same with the MUX Bus design. The size is doubled. However, the size/weight of the MUX BUS will continue to shrink as new LSI chips become available.
6	Bus Loading	There is no bus loading problem for a stand alone EMMADS System. (In the worst case, EMMADS bus loading is 7.42%)
7	Noise immunity	A digital signal offers better noise immunity than an analog signal.
8	Redundancy	Only MUX Bus type structure allows a cost-effective duplex redundancy

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